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5      **A TUBE FOR A NUCLEAR FUEL ASSEMBLY, AND A METHOD OF MANUFACTURING SUCH A TUBE**

10      The present invention relates to tubes of zirconium-base alloy suitable for use, in particular, for constituting all or the outer portion of the cladding of a nuclear fuel rod, and also to a method of manufacturing them.

15      Until now, use has been made above all of cladding made of a so-called "Zircaloy 4" alloy which contains tin, iron, and chromium in addition to zirconium. Numerous other compositions have been proposed, with content ranges that are often so broad that, to the person skilled in the art, they can be seen immediately to be purely speculative.

20      In particular, various alloys have been proposed with a niobium content lying in a range so broad that their resistance to thermal creep is quite poor at maximum values, whatever the metallurgical treatments used in making the alloy.

Alloys have also been proposed that contain, in addition to zirconium, tin to improve creep resistance, and iron.

25      An object of the invention is to provide tubes that have simultaneously good creep behavior and good resistance to corrosion, even in a high temperature medium containing lithium, while nevertheless being capable of being manufactured with a low reject rate, and being suitable for use in making cladding or guide tubes for fuel assemblies.

30      One of the causes of rejects is the formation of cracks during mechanical and heat treatments, giving rise to defects that make the tubes unacceptable. This risk exists particularly for high tin contents.

35      To achieve the above objects, there is provided a tube of zirconium-base alloy containing, by weight, 0.8% to 1.8% niobium, 0.2% to 0.6% tin, and 0.02% to 0.4% iron, the alloy being in the recrystallized state or in relaxed state, depen-

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Because of the relatively low tin content, recrystallization during metal-making can be performed at a relatively low

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10 In particular, the method may comprise the following steps:

- 20 to obtain a tube, with intermediate heat treatments at temperatures in the range 560°C to 620°C.

25 In general, the final heat treatment is performed in the range 560°C to 620°C when the alloy is to be in recrystallized state, and in the range 470°C to 500°C when the tube is to be used in relaxed state.

The alloy obtained in this way has resistance to generalized corrosion in an aqueous medium at high temperature, representative of conditions within a pressurized water reactor, that is comparable to that of known Zr-Nb alloys having high niobium content, and it has thermal creep resistance that is much greater than that of such alloys and that is

comparable to that of the best "Zircaloy 4" alloys.

By way of example, an alloy comprising 0.9% to 1.1% niobium, 0.25% to 0.35% tin, and 0.03% to 0.06% iron has been made. The metallurgical treatment sequence used comprised rolling over four cycles, with two-hour periods of heat treatment at 580°C interposed between the rolling step. The work hardening ratios and the recrystallization ratios were as follows:

	Work hardening ratio (%)	Recrystallization ratio (%)
First pass	40	70
Passes (2 or 3)	50 to 60	80
Last pass	80	100

Additional tests have been carried out for determining the influence of the iron and tin content on alloys having 1 % of niobium, with contents C, S<sub>i</sub> and O<sub>2</sub> in the above indicated ranges formed into sheets and processed up to  $\Sigma a = 5.23 \times 10^{-18}$ , with a final recrystallization step at 580°C. The corrosion tests were carried out:

- at 500° C, 415° C and 400°C in water steam
- at 360° C, in water containing 70 ppm of lithium.

The tests results are represented on the attached drawings, wherein :

- Figs. 1 and 2 give the weight increase of alloys according to the invention after 140 days in lithium containing water at 360° C, for different contents of Sn and Fe;

- Fig. 3 represents weight increase (which represents uniform corrosion), after 132 days at 400°C in water steam;

- Fig. 4, similar to Fig. 3, corresponds to an exposition

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5 - Fig. 6 is a graph indicating limits of zones in which the resistance to corrosion in different conditions is particularly favorable, making it clear that there is a particular interest in ranges 0.2-0.3% Sn and 0.15-0.3 Fe as regards resistance to corrosion.

Figs. 3 and 4 show there is an interest in an iron content higher than 0.2%, for enhancing the resistance to corrosion in water steam at 400°C and 415°C and reducing the undesirable effect of a high Sn content. Such Figures also indicate that the favorable results which are found for an alloy according to the invention are lost if there is a low tin content or no tin.

From a general consideration of all results, a composition range which is favorable regarding corrosion is defined by the three curves indicated in Fig. 6. Curve A limits a zone of interest as regards resistance in water at 360°C with a 70 ppm lithium content i.e. under conditions which are more severe than those which prevail in a reactor, as regards the lithium content. Curve B limits a zone in which there is satisfactory resistance in lithium containing steam at a temperature

slightly beyond 400°C. Last, curve C approximately corresponds to a limit of the acceptable contents as regards nodular corrosion resistance, in water steam at 500°C.

5 It is however possible to exceed the above indicated zone when some types of corrosion are not likely to occur.

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